NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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VI. Effectiveness of Yellow Filters

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Naval Medical Research and Development Command
Research Work Unit M0095.001-1040

Released by:

W. C. Milroy, CAPT, MC, USN
Commanding Officer
Naval Submarine Medical Research Laboratory

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S. M. Luria, Ph.D.
John Wong, HM2, USN
Roberto Rodriguez, HM2, USN

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APPROVED AND RELEASED BY

W. C. Milroy, CAPT, MC, USN
Commanding Officer
NAVSUBMEDRSCHLAB

SUMMARY PAGE

PROBLEM

To determine the extent to which yellow filters of different saturation (a) improve the visibility of targets and (b) interfere with color vision.

FINDINGS

Yellow filters produce a very slight, but statistically significant, improvement in the detection of large bright targets. They do not degrade the color vision of either normals or red-green dichromats when their excitation purity is less than 20%.

APPLICATION

These results show that a slight yellow tint to the filters in protective goggles will not interfere with color vision and may well produce some slight improvement in the ability to detect targets. There is, therefore, no objection to using filters with a slight yellow tint in the protective goggles issued to troops in the field.

ADMINISTRATIVE INFORMATION

This investigation was undertaken under Naval Medical Research and Development Command Work Unit M0095.001-1040 - "Protective devices for the eye in cold weather." This report was submitted for review on 1 Nov 1983 and approved for publication on 22 Nov 1983. It was designated as NAVSUBMEDRSCHLAB Report No. 1011.

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ABSTRACT

The visibility of bright and dark targets was compared when viewed through yellow filters whose excitation purity ranged from .06 to .98 as well as a neutral filter and whose total transmittances had been roughly equated. The visibility of large bright targets was enhanced by all the yellow filters but only to a very small degree. The visibility of the dark targets was also slightly enhanced, but these differences were not statistically significant. The color perception of both color normals and red-green dichromats was not affected by yellow filters whose excitation purity was less than .20.

INTRODUCTION

In a series of studies, we have attempted to specify the optimal characteristics of goggles designed to protect the eyes in the cold. We have studied the spectral transmittance of the filter necessary to protect the eyes from damage by the light-rays,[1] measured the degradation of performance resulting from the optical distortions found in a random sample of commercial goggles,[2] investigated the limits of optical distortion which do not significantly degrade performance,[3] measured the resistance to fogging of numerous goggles,[4] and determined the preferred density of these filters.[5] Another question is whether or not the filters in these goggles should have a yellow tint.

Yellow goggles are quite popular under conditions of poor visibility particularly with outdoorsmen and skiers. Luckiesh[6] reported nearly 70 years ago that yellow or amber glasses were beneficial in riflery. Twenty years later, Luckiesh and Moss[7] stated that "yellow-green glasses are likely to aid the definition of the image of the target." There is considerable agreement among the people who wear them that yellow goggles improve visibility. In trying to explain this, it seemed reasonable to assume that any improvement in visibility was the result of the reduction in chromatic aberrations. Wald and Griffin found that the amount of chromatic aberration increases as wavelength decreases, and below 500 nm it increases markedly.[8] Wald remarked that the only defense is to exclude those wavelengths which cause the greatest visual disturbance, and it is precisely this which is accomplished by yellow filters. Yet most subsequent experiments failed to show that yellow filters were effective,[9] and Wyszecki[10] concluded from a theoretical analysis that no colored filter could be expected to improve performance compared to a neutral filter.

Nevertheless, many years ago, Fry[11] wrote to us, "I am inclined to suspect there may be some basis for their use which I do not fully understand." There was indeed some basis for continuing to consider the possibility that the popularity of the yellow filters rested on more than a vague, undefined "psychological" phenomenon.[12] Richards, among others, suggested that the tests of yellow filters had failed because of too little blue in the environment;[13] that is, the yellow filters could be expected to be effective only when both short and long wavelength stimuli were present.

Luria[14] measured the visibility of blue and yellow targets against blue, green, and yellow backgrounds while wearing yellow and neutral filters. The yellow filters improved the detection of yellow targets as the wavelength of the background decreased, as would be expected. In addition, the yellow filters were more effective with younger subjects, which is also not surprising since the ocular media tend to yellow with age. More difficult to explain at the time, however, was the finding that the yellow filters were increasingly effective as the size of the target increased. It suggested, however, that another reason that the tests of the effectiveness of yellow goggles had failed was that a test of resolution acuity was not as appropriate a test as detection of larger targets. Recently, therefore, Kinney et al[15] conducted new tests of the efficacy of yellow goggles using as their measure the ability to discrimate differences in the depth of large shallow depressions in the snow. They found in fact that using this measure the percentage of correct judgments was significantly greater with yellow than with neutral goggles.

Even if yellow filters facilitate the detection of large targets, it does not necessarily follow that they should be incorporated in goggles. Farnsworth[16] pointed out some time ago that "strong" yellow filters could prevent prompt recognition of colored signal lights, particularly by color defectives, an opinion echoed by many other authorities since then.[9] Moreover, there are reports that some individuals dislike the yellow filters.[17,18] The question arises, therefore, are highly saturated filters necessary to achieve an improvement in target detection? Or is it the case that yellow filters of relatively low saturation, which would not interfere with color vision, might also produce some improvement of target detection?

Two sets of experiments were carried out. First, the ability of subjects to detect both bright and dark large targets on a white background was compared when they wore either yellow filters ranging in purity from .06 to .98, or a neutral filter. In addition, the color vision of both normal and dichromatic subjects was measured while wearing the various filters.

EXPERIMENT I
Detection of Bright Targets

Method

Filters - Six Kodak filters ranging in excitation purity from .06 to .98 were tested. The filter characteristics are given in Table I, and their spectral transmittance, measured with a Cary spectrophotometer, Model 14R, are shown in Fig. 1. Each filter was mounted in a pair of safety goggles, one pair of which served as the achromatic control, and roughly equated for total transmittance with neutral density filters. Their C.I.E. coordinates are plotted in Fig. 2.

Table I. Characteristics of the yellow filters

Kodak Number	Purity	Dominant Wave-length	Transmittance
--	.00	--	.58
2B	.06	570	.59
2E	.11	570	.63
HF-5	.18	577	.60
3	.50	572	.61
8	.85	572	.61
12	.98	576	.55

Targets - A bright circular spot, 2 degrees in diameter was projected by a Kodak Carousel projector on a 16x25 degree screen set 2 m from the subject. The screen faced south toward an open door to the outside but was not illuminated directly by the sun. The subject sat just inside the door. Sessions were run only when the sun was shining between 11:00 AM and 3:00 PM in order to keep the light level

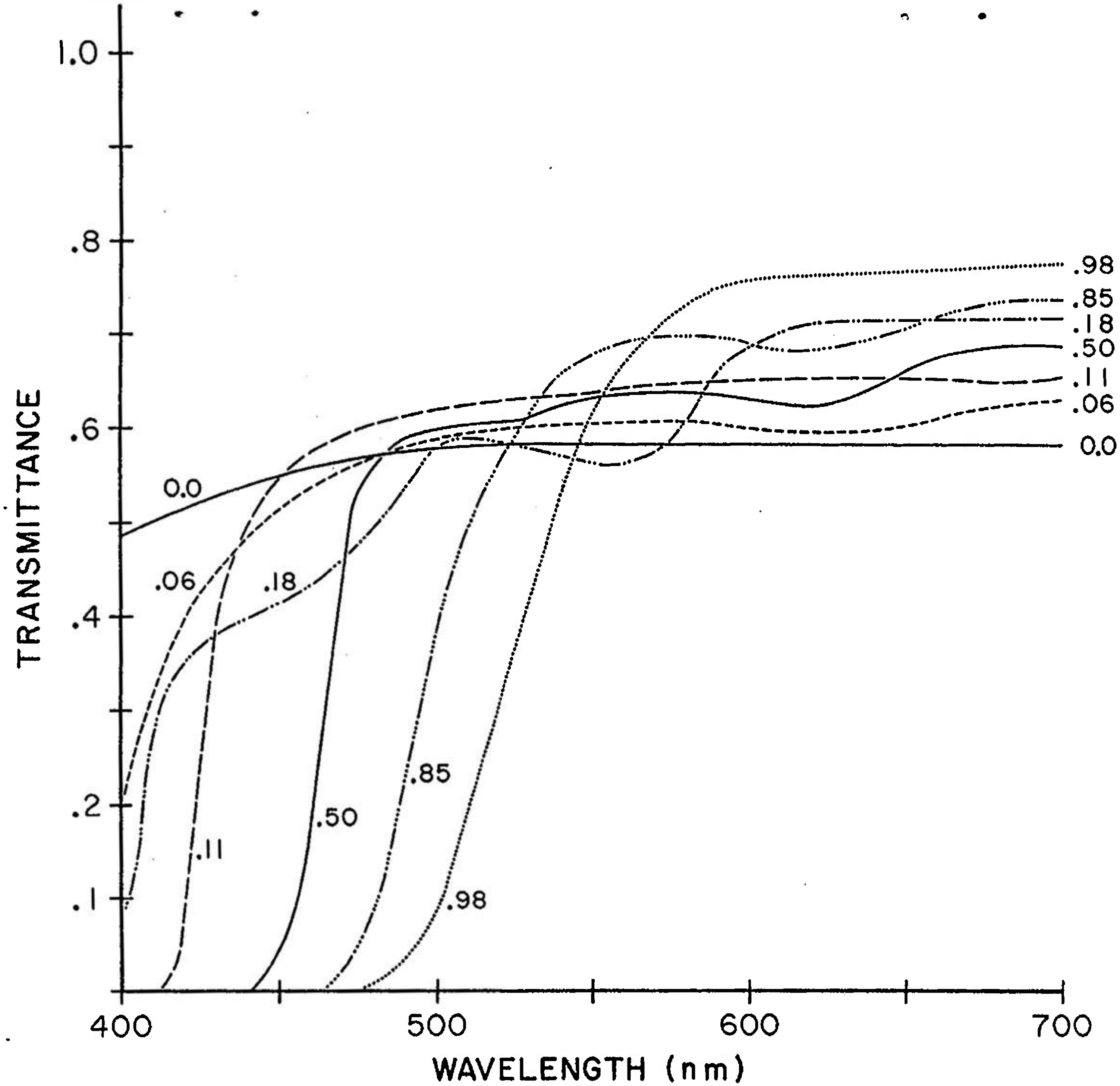

Fig. 1. The spectral transmittances of the filters with their neutral density additions mounted in the safety goggles.

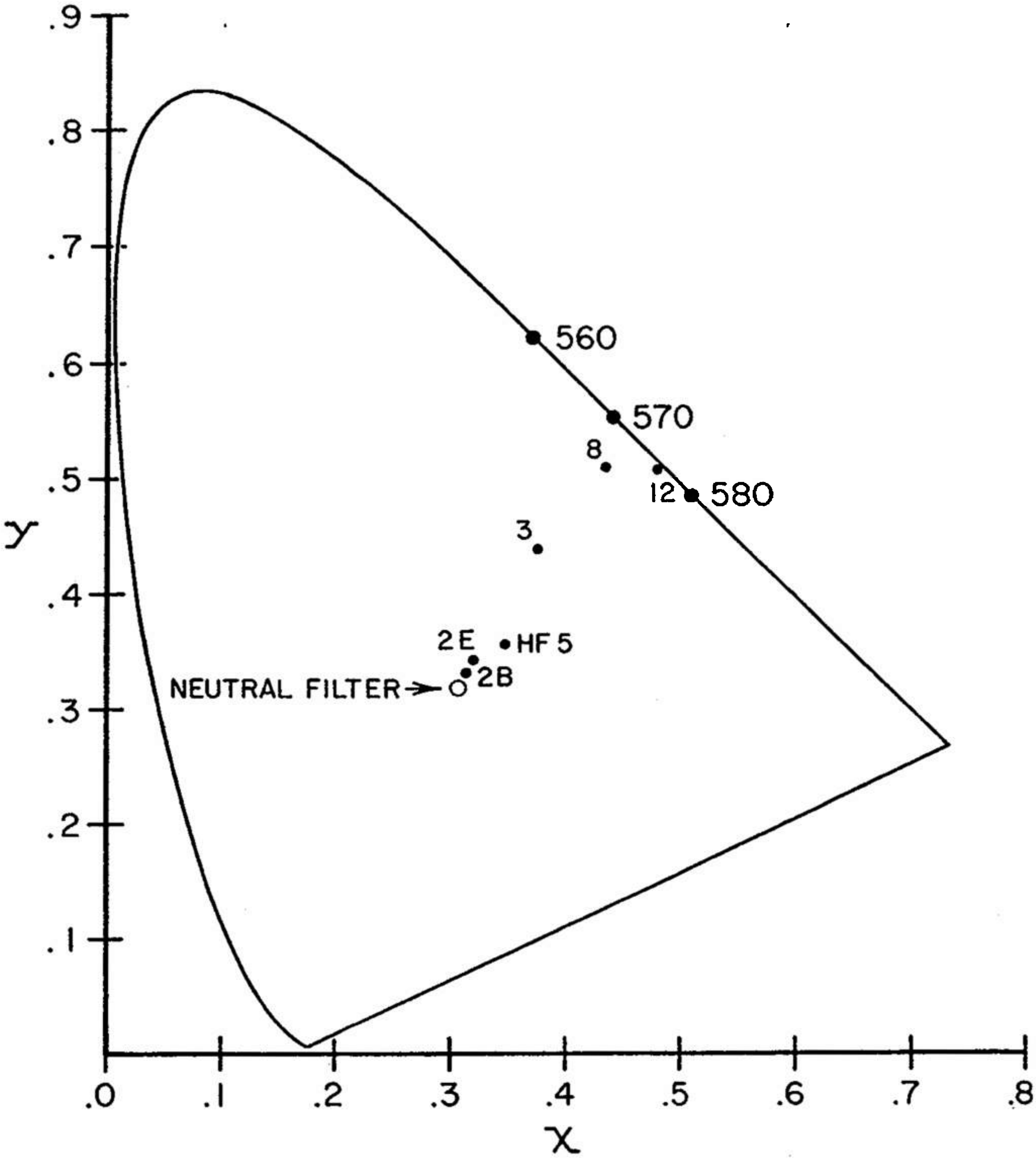

Fig. 2. The C.I.E. coordinates of the 6 yellow filters (identified by their Kodak catalogue numbers) and the neutral filter.

relatively constant. The target was produced with an opaque slide with a hole in the center. The brightness was controlled in 0.1 log steps with neutral density filters placed between the projector and the screen. The white background of the screen was illuminated to about 60 foot-Lamberts (200 cd/m^2).

Procedure - The subjects wore the various filters in counter-balanced order. Each subject put on the first pair of filters and was shown the target at an easily visible brightness. He was told that the intensity of the spot could be varied; targets of various brightnesses were then displayed. He was cautioned that a target would not be shown on every trial, and he should not guess. He was instructed to report the presence of the target when he saw it.

Thresholds were measured with the method of constant stimuli. A range was first determined for the subject by the method of limits, giving the approximate intensities at which he could see the target nearly every time and at which he usually could not see it. Four or five evenly spaced target intensities between these end points were set, and these were presented in random order until there were five presentations of each. The targets of various brightnesses were presented for about two seconds. The resulting frequency-of-seeing curve was plotted on probit paper and the 50% point taken as the threshold.

Subjects - Fourteen members of the laboratory or their dependents, ranging in age from 15 to 31, served as subjects.

Results

The results are presented in terms of the density of the filter which was interposed between the target-slide and the screen at threshold. The solid line in Fig. 3 shows the mean density of the neutral filter at the target-threshold for the 14 observers through each of the yellow filters in the goggles. The density of the neutral filter is, of course, an index of the subject's sensitivity: as sensitivity increases, the density through which the target can be seen increases.

Figure 3 shows that the target was seen through higher densities of filter (that is, at lower luminances) with every one of the six yellow filters than with the achromatic filter. Unexpectedly, the yellow filters of low purities appeared to be more effective than the more saturated ones. A Friedman analysis of variance by ranks[20] showed the filters to be significantly different ($p<.01$), and the Wilcoxon Matched Pairs Signed Ranks test[20] showed that the neutral filter was significantly different from the yellow filters of 6% purity (.01), 11% purity (.02), and 18% purity (.01). It should be noted, however, that the significant differences amount to about 0.1 log unit of density.

EXPERIMENT II

To check these results, the experiment was repeated with a different procedure and additional subjects, but with the same filters and target-sizes.

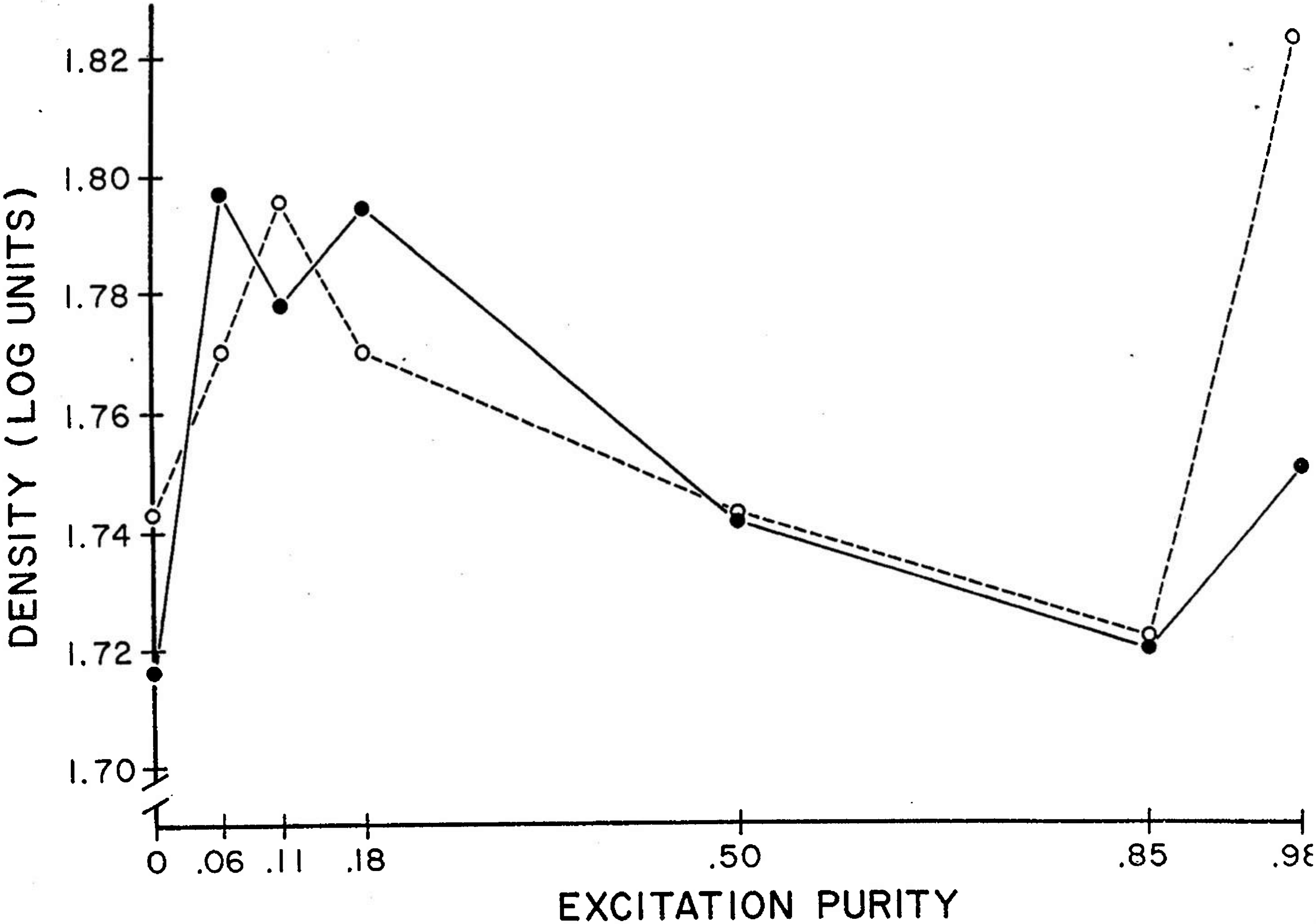

Fig. 3. Mean neutral density of the filter through which the subjects could detect a bright target with each of the seven pairs of goggles. As sensitivity increases, the density of the filter through which the target is still visible increases. The solid line shows the results in Expt. I. The broken line shows the results of Expt. II.

Method

Procedure.- The target was produced with a hole in one corner of an opaque slide. By rotating the slide in the projector, the spot could be made to appear in any corner of the screen. The subject put on a pair of filters and was first shown the target in each of the corners and told that it would appear in the corners randomly at increasing intensities until he could detect it. He was cautioned that a target would not be shown on every trial, and, indeed, about 10% of the trials were blanks.

Thresholds were measured with the ascending method of limits. The target intensity was first set below the subject's threshold; if the target was not reported, the intensity was raised by 0.1 log unit. If it was reported, the target was presented a second time at the same intensity in a random location. The threshold was the intensity at which the target was correctly reported twice. Then the subject donned another pair of filters and the procedure was repeated. The subjects wore the filters in counterbalanced order.

Subjects - Fourteen members of the laboratory served as subjects, seven of whom had served in Experiment I. Their ages ranged from 19 to 31.

Results

The results are again presented in terms of the density of the filter which could be interposed between the target-slide and the screen at threshold. The broken line in Fig. 3 shows the mean density of the neutral filter at the threshold for the 14 observers through each of the goggles. There is clear agreement between the results of the two experiments. The thresholds in Expt. II, however, are not significantly different from each other, according to the Friedman analysis of variance by ranks, which can probably be attributed to the lesser precision of the method of limits compared to the method of constant stimuli used in Expt. I. It is not clear why the filters with .85 excitation purity produced relatively poor target detection and the filter with .98 purity was noticeably better.

EXPERIMENT III
Detection of Dark Targets

In our previous experiments in the snow,[16] we wondered if the yellow filters improved the detection of the darker patches of the terrain rather than the lighter patches. We were interested, therefore, to measure the detection of dark rather than bright targets through the yellow filters.

Method

Targets - The dark spots were produced with a series of photographic negatives of light spots of different intensities photographed against a black background. A series of 20 of these negatives were selected with dark spots of various contrasts ranging from invisible to noticeably above threshold. The dark spots were mounted in a corner of the slide, so that by rotating the slide in the projector, the spot could be projected in any of the corners of the screen. The projected spots were again 2° visual angle when projected at a distance of 2 m from the subject.

Procedure - The subject put on a pair of filters and was shown the dark spot in each of the four corners.

He was told that the contrast of the spot could be varied, that a spot would not be shown on every trial, and he was to report the position of the spot when he saw it. He was then shown the series of 20 slides in random order with the spots projected to random corners of the screen, and the number of correct responses was tabulated. He then donned another pair of filters, and the series of slides was shown in a different order and his score again recorded. The subject wore the various filters in counterbalanced order.

Subjects - Fourteen staff members ranging in age from 15 to 53 volunteered to serve as subjects. Five had served in one of the previous experiments.

Results

The mean number of targets detected with each of the yellow filters ranged from 6.8 to 7.3 (Fig. 4). The differences in the number of targets detected through the yellow filters were very small and not significiant according to an analysis of variance by ranks. More targets were detected however with every yellow filter except the least saturated than with the achromatic filter.

EXPERIMENT IV
Color Vision

There have been a number of studies dealing with the problem of the effects of tinted lenses on color vision. They have for the most part dealt with commercial lenses, and thus the colors and saturations tested have been those which happened to have been manufactured.

Some investigators have reported no changes in color through tinted lenses,[21-23] whereas others have found some degradation when tested with an anomaloscope.[24-26] This test is the most sensitive and the most likely to demonstrate a change in color vision, but Clark[27] has cautioned that the anomaloscope results may not be valid for real life scenes.

Farnsworth[28] measured the effects of eight different colored lenses on performance on the Farnsworth-Munsell 100-Hue Test. Only two degraded color vision. Farnsworth reported the C.I.E. oordinates of his lenses, making it possible to calculate their excitation purity. The two lenses which degraded color vision were the only ones in the yellow region, but they were also the only filters with purities of about 50 and 90%; the purities of the other lenses did not exceed about 25%. There was no attempt to control the relationship between hue and saturation. Indeed, we have found only two studies which systematically varied saturation.

Chisum et al[29] tested the effects of three filters (with cutoffs at 500, 525, and 550 nm) on the ability to discriminate colors used on aeronautical charts. Under white light the degradation of color perception was statistically significant only through the most saturated filter (550 nm cutoff), but it was very small and did not appear to be of practical importance. Indeed, Chisum et al concluded that a low density yellow filter may be desirable, since several of the subjects--as often happens--remarked that it seemed to enhance vision.

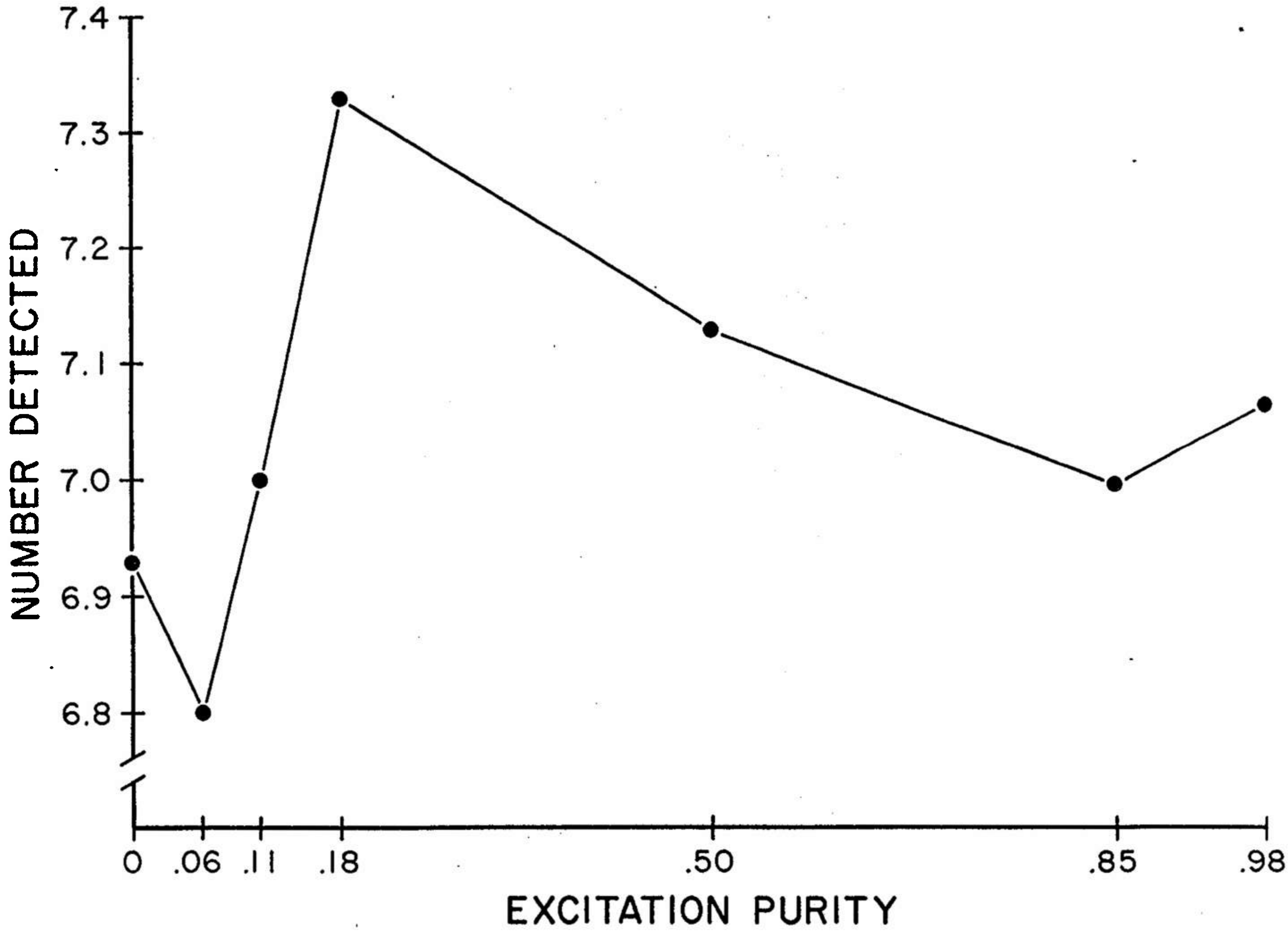

Fig. 4. The mean number of dark targets detected through the various filters.

Verriest et al[30] tested the effects of seven yellow filters (dominant wavelength about 580 nm), varying in both saturation and transmittance on four tests of color vision: pseudo-isochromatic plates, Farnsworth's D-15, 100-Hue, and an anomaloscope. Only one of his filters was the typical sharp cutoff filter with close to 100% transmittance in the long wavelenths. All but one of the others transmitted wavelengths throughout the spectrum, with linearly increasing transmittance as the wavelength increased; the maximum transmittance at 700 nm ranged from .10 to .50. The excitation purity ranged from about .10 to about .95. Total transmittance was not controlled.

Verriest et al found that the subjects were able to read the pseudo-isochromatic plates and the D-15 panel with every filter except the most saturated. With the 100-Hue test, the mean error scores increased with an increase in purity and an increase in density. However, the authors pointed out that most of the increase could be attributed to only 5 of the 42 subjects and these were considered to be mild color defectives; the others maintained normal color discrimination with all filters except the most saturated. The anomaloscope readings were altered by all the filters except the least saturated. Verriest et al concluded that the color discrimination of most subjects remained within normal limits as long as the difference in density between the 400 and 700 nm points did not exceed 2.5 log units and the illumination did not fall below 35 ft-L. They agreed with Farnsworth's[17] conclusion that filters should have an upper limit of 25% purity for lenses to be worn by color normals. Clark[9,31] has calculated that purity should be less than 20% in order to preclude any interference with the vision of color defectives. Several investigators have pointed out that color defectives may be disproportionately affected.[32,33]

In this study, the excitation purity of yellow filters of approximately equal transmittance was varied and the color perception of color normals and defectives was measured.

Method

Subjects - Four color normals, two deuteranopes and a severely anomalous protanope, as determined by U. S. Navy color vision test battery,[34] served as subjects. The ages of the normals ranged from 11 to 39 and those of the color vision defectives from 28 to 53.

Tests - The subjects were given the following tests in this order: the American Optical Co. Armed Forces Pseudo-isochromatic plates, Farnsworth Lantern, D-15, H-16, and the F-M 100-Hue test. All tests were administered under the daylight illuminant of the Macbeth Spectral Light, Model SPL-65L/1.

Procedure - The seven filters, used in the previous experiments, were worn by the subjects in counterbalanced order.

Results

The Pseudo-isochromatic Plates - None of the color-normals made an error on the plates with any of the filters (Table II). The three color-defectives made an average of 10.7 to 12 errors with the various filters. The number of errors made by each subject was almost completely constant

Table II. Mean errors on color vision tests by color normals and color defectives with various yellow filters

Test		Excitation Purity						
		.00	.06	.11	.18	.50	.85	.98
Pseudo-isochromatic plates	Normal	0	0	0	0	0	0	0
	Dich.	11.6	11.7	11.7	12.0	11.5	11.0	10.7
Farnsworth Lantern	Normal	0	0	0	0	0	0	0
	Dich.	19.0	19.3	15.3	15.3	18.8	17.3	16.3
D-15	Normal	0	0	0	0	0	14.25	22.75
	Dich.	*	*	*	*	*	*	*
H-16	Normal	0.25	0.50	1.00	1.75	1.75	8.50	16.75
	Dich.	**	**	**	**	**	**	**

* The deuteranopes and the protanope gave the expected distinctive pattern of results.

** The deuteranopes gave the distinctive pattern; the protan made no errors until purity reached 85%

from one filter to another. The deuteranopes made 10 or 11 errors with each filter, and the protan made 14 errors with each filter.

The Farnsworth Lantern - None of the color-normals made an error on the Lantern with any of the filters. The color-defectives averaged 17.3 errors across all the filters, and again this did not vary with the purity of the filter.

D-15 - None of the color-normals made an error on the D-15 until the filter purity reached 85%. The defectives, of course, could not pass the test. At purities of 85% and 98%, the typical pattern made by deuteranopes began to disappear, and they began to make haphazard responses.

H-16 - One of the color normals made one error with the achromatic filter and two errors with the .06 filter, no doubt through carelessness. He made no errors with the other filters of less than 85% purity. The mean number of errors with each filter by the normals ranged from a mean of 0.25 at a purity of zero and increased to a mean of 1.75 at a purity of 98. Both deuteranopes failed the test at all filter purities, and their responses became haphazard at the two highest purities. The protan made virtually no errors until the two highest purities.

F-M 100-Hue - The mean error scores for both groups of subjects is shown in Fig. 5.

The error scores were stable for both the normals and dichromats through a filter purity of 18%. With a purity of 50%, the error scores doubled for both groups, and continued to rise for the normals with filters of the highest purity; the dichromats could not even make a reasonable attempt at performing the task with these filters.

Discussion

Except for the 100-Hue test, the color-normals did not make any errors until the excitation purity of the yellow filters exceeded 50% (other than the apparently careless errors by one on the H-16). These tests were, of course, designed to reveal only red-green deficiencies. The critical test was the 100-Hue test, and on that the mean error rate began to increase markedly at a purity between .18 and .50. The present results, therefore, conform to the conclusions of Clark,[9] Farnsworth,[28] and Matthews et al[32] that the purity of tinted filters should not exceed 20 to 25%. Below that, there appears to be no interference with color vision for either color-normals or dichromats.

GENERAL DISCUSSION

These results indicate that yellow filters do, indeed, improve the detection of relatively large targets exposed for long periods of time. Although they may not improve visual acuity, they conform to the results that Kinney et al[16] obtained in the field. The improvement in target detection, while very small, appears to be a genuine phenomenon.

Yellow Filters in a Chromatic Visual Field

It is not completely surprising that acuity has not been shown to be reliably improved by yellow filters. It is well known that visual acuity is generally not affected by variations in spectral distribution.[35] On the other hand, visibility is markedly affected by both the spectral sensitivity of the target and the combination of target and surround;[35] and as the color difference between the two increases, visibility increases.[36] Thus, if there is color in the visual scene, the introduction of a yellow filter allows the yellow colors in the visual scene to reach the eye. As the spectral distribution of another color diverges from yellow, it is increasingly filtered out. This, of course, increases the contrast with the yellow. On the other hand, the very fact that the spectral distribution of the color is diverging from yellow means that it is becoming more discriminable from yellow to begin with. This must be a reason why the yellow filters, on balance, improve discriminability to only a small degree: the improvement in contrast which results from the introduction of a yellow filter is related to the improvement in contrast which is occurring without the yellow filter. At best, the former is only marginally greater than the latter.

Another line of explanation is illustrated in Fig. 6 which presents the C.I.E. coordinates of hypothetical green and orange targets seen through a yellow filter of high or low purity (Fig. 7). The green and orange

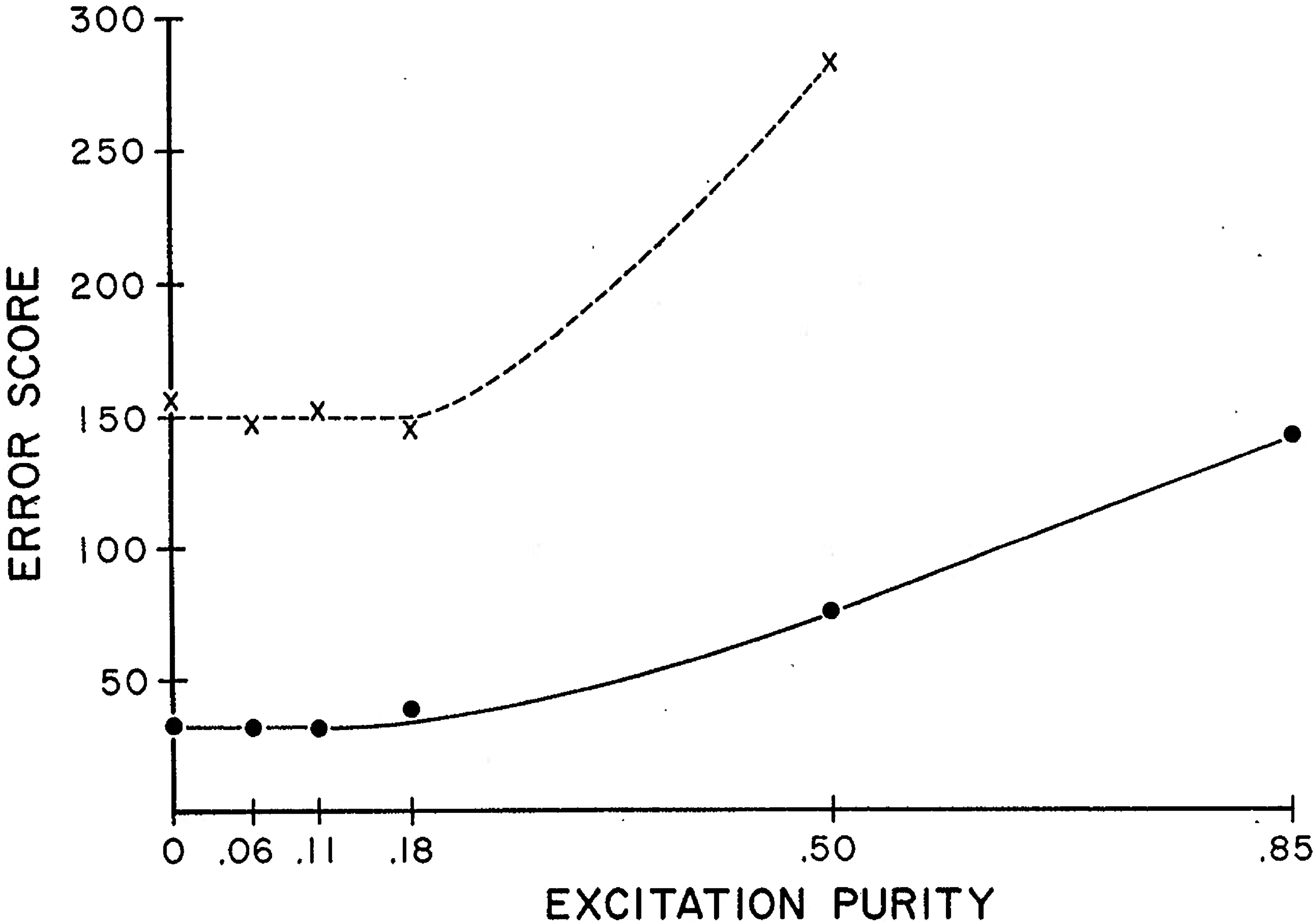

Fig. 5. The mean error scores on the Farnsworth-Munsell 100-Hue test made by color normals (solid line) and color defectives (dashed line) through the various filters.

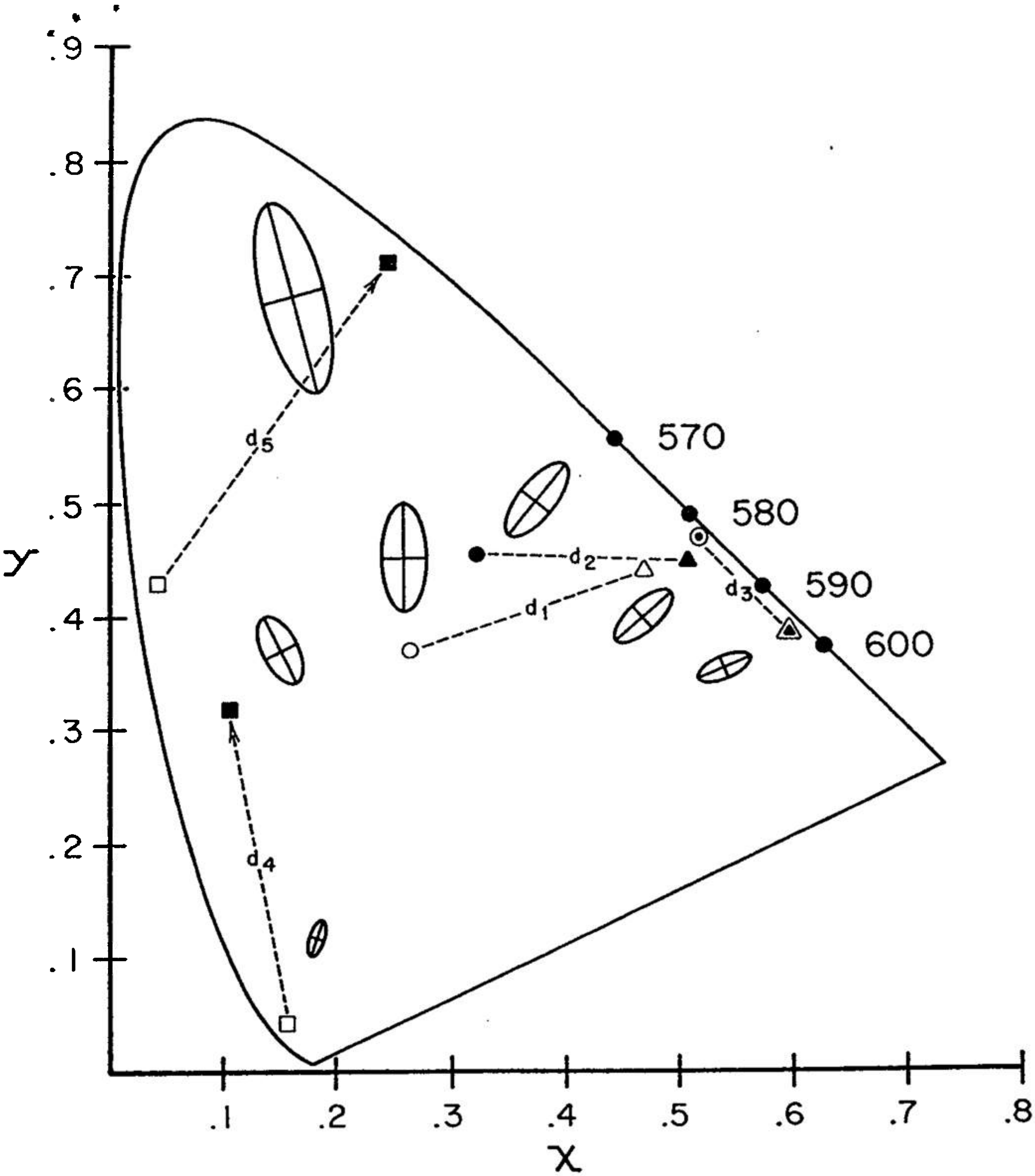

Fig. 6. C.I.E. chromaticity coordinates of the desaturated green (O) and orange (Δ) targets shown in Fig. 7. When seen through the low purity yellow filter in Fig. 7, the coordinates are shifted from their positions along track d_1 to positions on track d_2; when seen through the high purity yellow filter, they are shifted to positions along track d_3. A saturated green and a saturated blue target which lie along track d_4 would be shifted to positions on track d_5 when seen through a high purity yellow filter. The ellipses are MacAdam's[37] isochromatic ellipses.

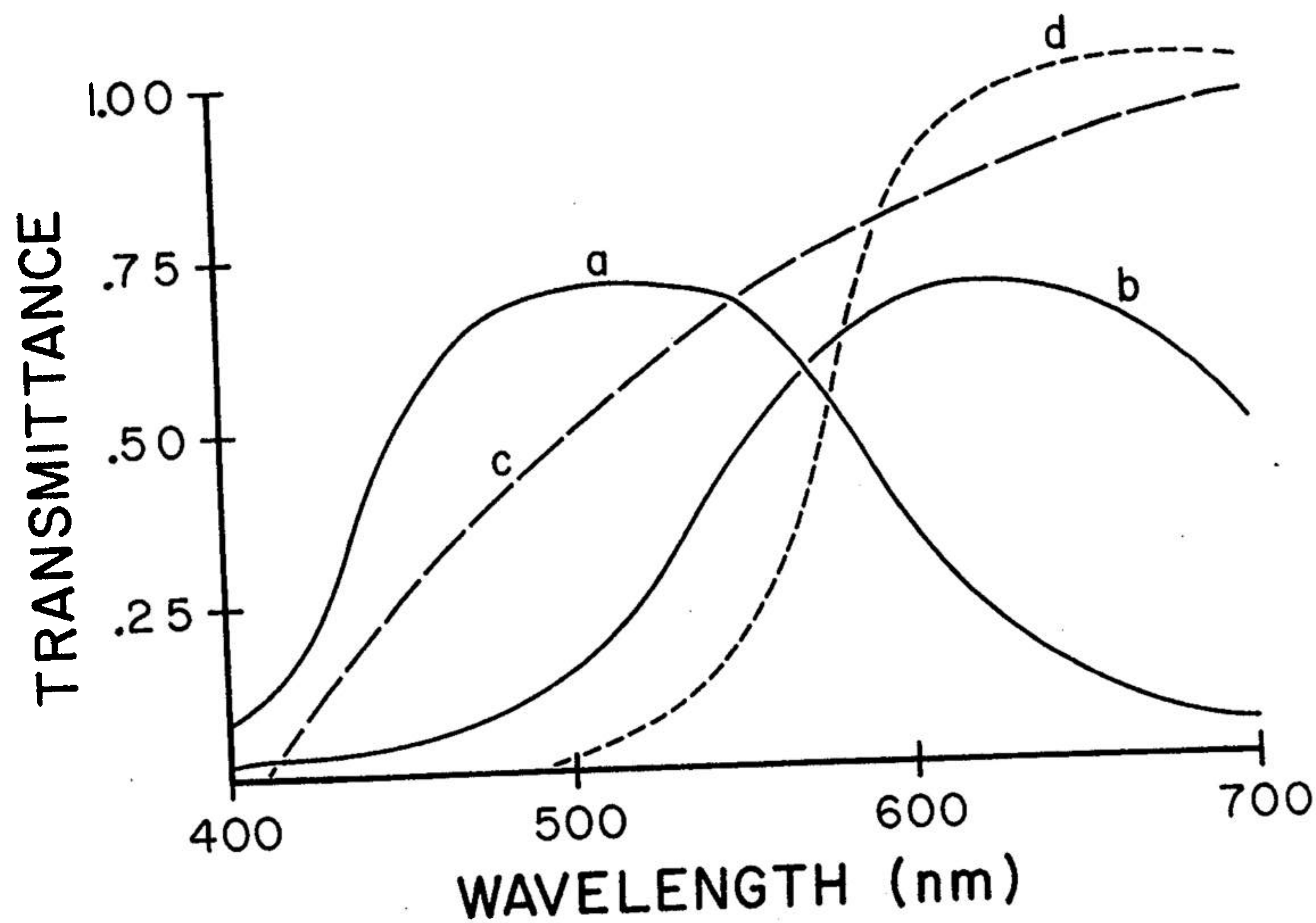

Fig. 7. Spectral transmittance curves of hypothetical green (a), orange (b), high purity yellow (c), and low purity yellow (d) filters.

targets are well separated on the C.I.E. diagram (d_1). When seen through a yellow filter of low purity, their apparent chromaticity is, of course, altered, and their separation is reduced (d_2). In an isometric color space, this would indicate that it is harder to discriminate them. The C.I.E. diagram, however, is not chromatically isometric; some of MacAdam's[37] isochromatic ellipses are plotted in Fig. 6, and it is apparent that the yellow filter shifts the hues toward a portion of the diagram in which the isochromatic spaces are appreciably smaller and color discrimination of two hues of a given separation on the diagram is, therefore, easier. When the two targets are seen through a filter of high purity, they are further shifted into a portion of the diagram in which the ellipses are even smaller (d_3). Thus, although they are positioned more closely on the diagram, the reduced separation is more than balanced by the reduced isochromatic color space.

Figure 6 suggests that green filters would shift the hues toward regions of larger ellipses without a corresponding increase in separation and would, therefore, degrade discrimination; Fig. 6 also suggests that blue filters would improve discrimination by shifting chromaticities toward regions of smaller ellipses, but improved discrimination is not always the case.[14] In any event, blue filters are objectionable on other grounds.[1,38]

Yellow Filters in an Achromatic Visual Field

Yellow filters are not as effective with targets that are not yellow.[14] Outdoorsmen often note that they are most effective toward dusk or in hazy conditions. It is, of course, under these conditions that the spectral distribution of the ambient light shifts toward the longer wavelengths. With blue and green targets, the yellow filters shift the chromaticity coordinates to regions with larger ellipses (d_4 and d_5 show the shift for a blue and blue-green target when they are combined with a high purity yellow filter) which suggests that yellow filters would not improve the detection of those targets.

When the visual scene is achromatic--as it may be in the snow and was in these experiments--then the yellow filters may be effective for another reason, as has been pointed out by Kinney et al.[16] This explanation is based on recent theories of color vision. Opponent-colors theory[39] holds that contrast phenomena result from the induction of an opposite response rather than simply depressing sensitivity. Further, recent zone theories of color vision[40,41] postulate that the perception of brightness is mediated by the outputs of both achromatic and chromatic systems; when the eye is stimulated by the full spectrum, opponent activity negates some of the response, reducing the physiological response and the perception of brightness. Theoretically, the yellow goggles eliminate the shorter wavelengths and their negative contribution to the chromatic system, resulting in a larger physiological response and an increased perception of brightness.

Yellow Filters and Color Vision

These results indicate that the yellow filters do not interfere with that until the excitation purity exceeds a value of 18%. They conform, therefore, with the recommendations of Farnsworth[28] and Clark[9] that the upper limit of purity be 20 to 25%. It is interesting that the color defectives in this study were no more affected by lower purities than were the normals.

In summary, we conclude then that a slight yellow tint (no more than 20%) to the filters in protective goggles might well be of some beneficial effect without interfering with color vision of either normals or red-green dichromats.

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The visibility of bright and dark targets was compared when viewed through yellow filters whose excitation purity ranged from .06 to .98 as well as a neutral filter and whose total transmittances had been roughly equated. The visibility of large bright targets was enhanced by all the yellow filters but only to a very small degree. The visibility of the dark targets was also slightly enhanced, but these differences were not statistically significant. The color perception of both color normals and red-green dichromats was not affected by yellow filters whose excitation purity was less than .20.

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